Impact Crater Detection on Mars Digital Elevation and Image Model

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- Crater Detection
  - Scale Invariant Feature Transform
  - Multi Population Genetic Algorithm
- Basin Detection
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- Crater Verification
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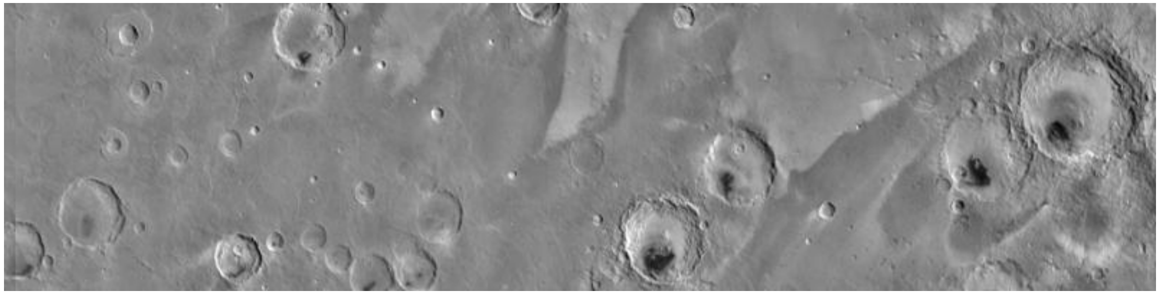
Problem Definition

- The extraction of Martian impact craters.
- Two different datasets. (Optical, Elevation)

(A)



(B)

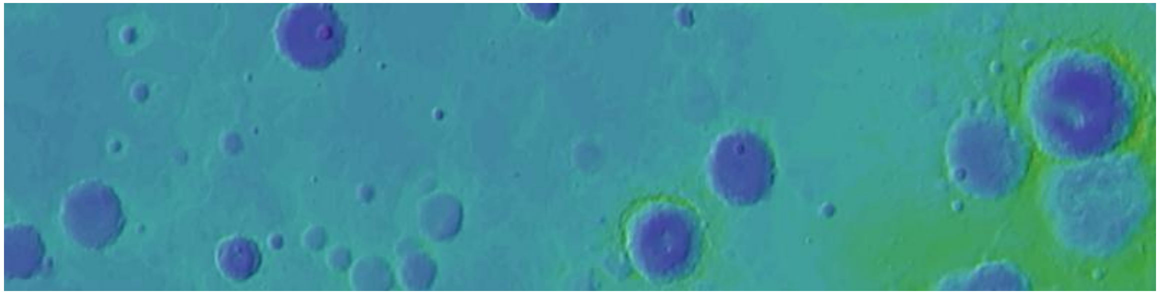


Figure 1 : (A) Image acquired from Mars Digital Image Mosaic (B) from Mars Orbital Laser Altimeter, both acquisited on 0.15’ West, 9.36’ North, 14.46’ East, 12.67’ South.

Overview of the Algorithm

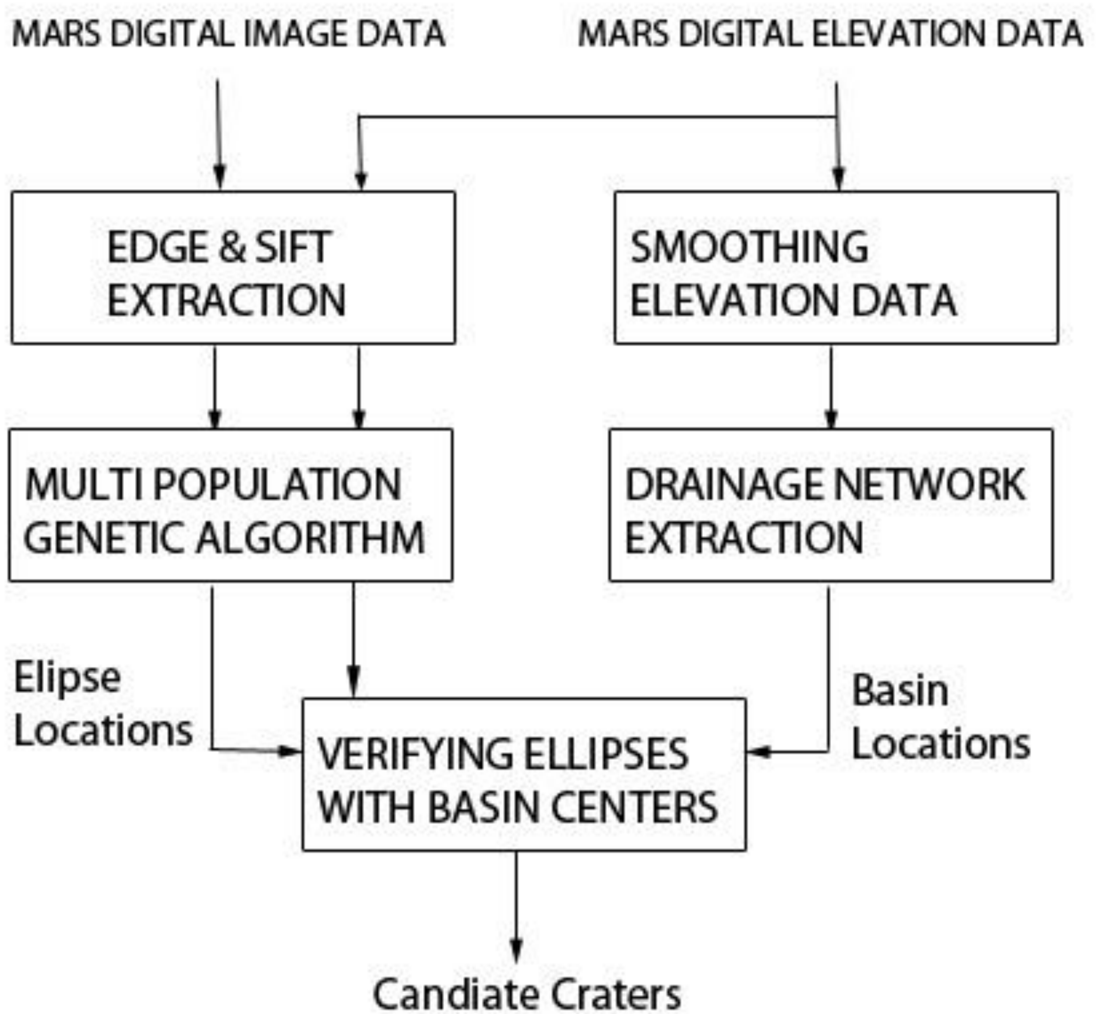


Figure 2: Architecture of the System developed.

Crater Detection

- Crater rims are repsented as ellipses.
- Ellipse representation is problematic.
  - Degradation of craters due to erosional processes.
- Two staged of solution :
  - SIFT + Edge point detection
  - Multi-Population Genetic Algorithm

Scale Invariant Feature Transform

- Proposed by Lowe [1].
- Transform into collection of feature vectors that are invariant to
  - Scaling , rotation & Illumination changes.
- Good localization on crater rims :

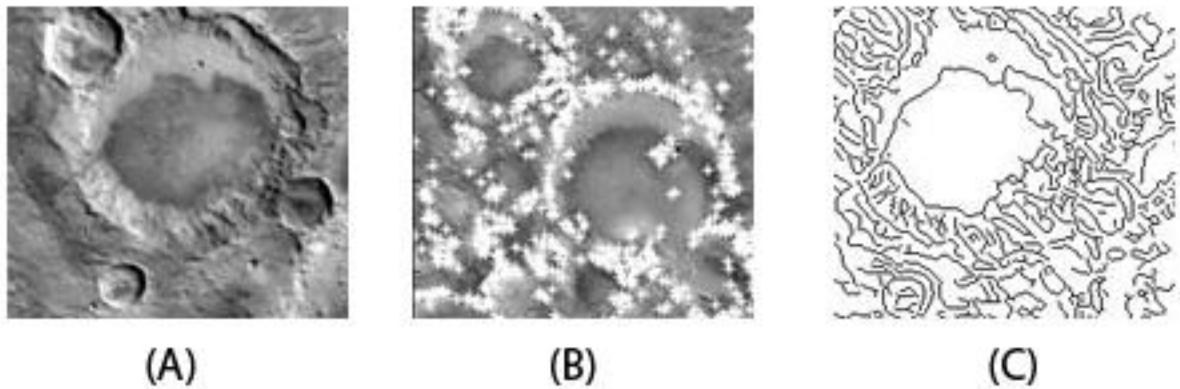
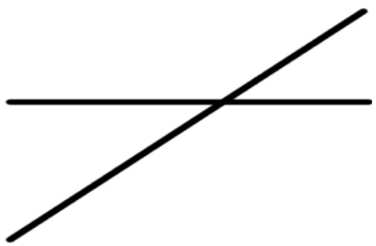


Figure 3: (A) Optical data obtained from Mars surface (B) SIFT features highlighted (C) Edges extracted by canny edge detector

Ellipse Detection Algorithms

- Literature of Martian Impact Crater Detectors use Hough Transform based methods.
- Hough Transformation (HT) :
  - Image space to parameter space



  - Parameter space grows exponentially along with number of parameters.
    - Appropriate for simple primitives such as lines.
    - Huge complexity for ellipse detection.

Ellipse Detection Algorithms

- Randomized Hough Transform (RHT) :
  - A solution to the complexity problem of HT.
  - Randomly sample a number of points.
  - Calculate subset of parameter space.
  - Randomness can be traded with Accuracy.
- A blind search on parameter space.
  - No feedback information from the ellipses.

Ellipse Detection Algorithms

- Genetic Algorithm (GA) :
  - Solution to the problems associated with RHT.
    - Evolve solutions using the feedback of their fitness.
  - Find an approximate solution to the optimization problems.
  - Sketch of the Algorithm
    - Until Convergence
    - Evolve the solutions to find fittest one.
    - Evolution : Mutation & Crossover.
  - Globally optimal ellipse ?
    - We prefer multiple locally optimal ellipses.

Ellipse Detection Algorithms

- Generalize GA to find multiple local optimas.
- Sharing Genetic Algorithm (SGA) :
  - Fitness of similar individuals is shared.
  - Search is guided towards uninhabitat areas.
  - Locally optimal ellipses are promoted.
- Multi-Population Genetic Algorithm (MPGA) :
  - A number of ‘islands’ that can communicate.
  - Better performance on ellipse detection [2].

Multi-Population Genetic Algorithm

- Multiple populations promote local optima search.
- Sketch of the algorithm.
  - Evolve a number of solutions (ellipses).
  - Each solution lives on closest island.
  - No island close enough ?
    - An individual (ellipse) can create her own island.
  - Input : SIFT features + Edges
  - Output : Ellipses

Multi-Population Genetic Algorithm

- An iteration of MPGA :

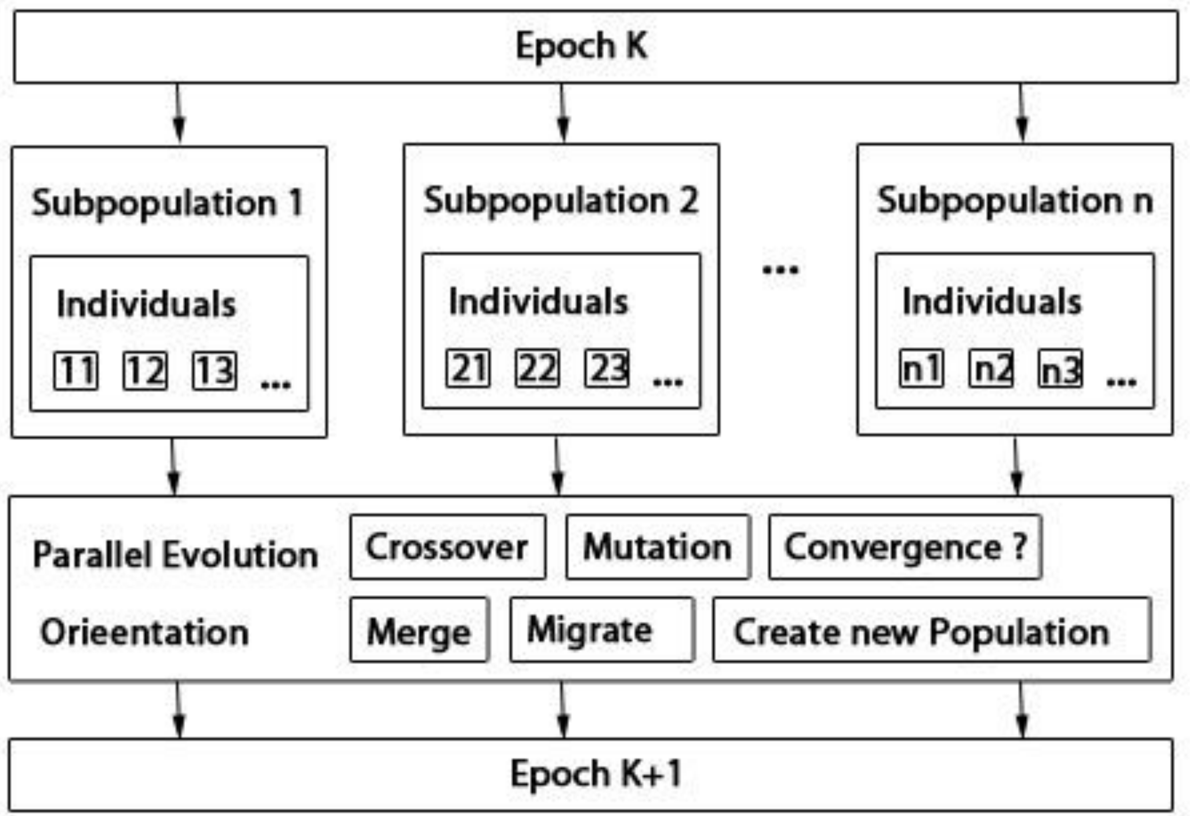


Figure 4: One iteration of Multi-Poulation Genetic Algorithm

Multi-Population Genetic Algorithm

- How to represent an individual solution ?
  - Directly by parameters of ellipse [3]
    - Search towards non-existent ellipses.
  - The minimal number of points that are able to characterize an ellipse [2].
    - Five keypoints are enough.

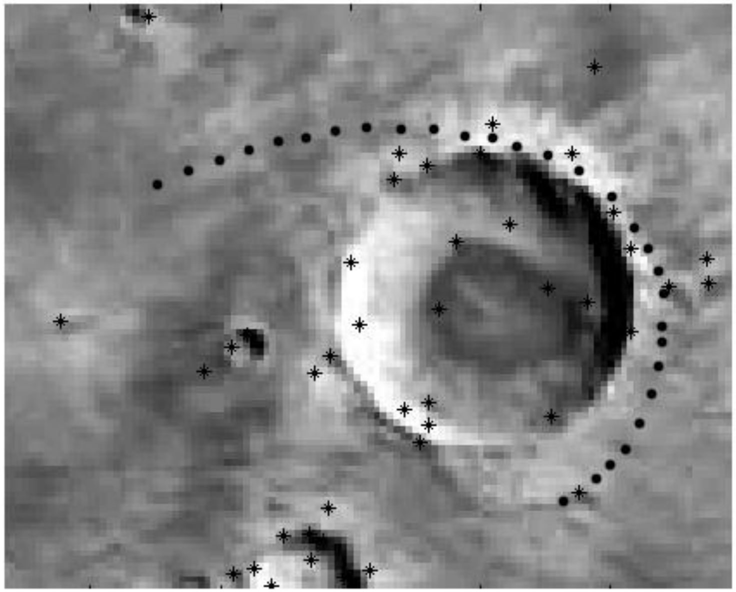


Figure 5: An individual which represents an ellipse determined by five SIFT keypoints.

Multi-Population Genetic Algorithm

- How to evaluate the fitness of an individual.
  - Match the template of ellipse around edges [2].
    - For Martian impact crater detection : Edges do not clearly distinguish craters.

$$f_1 = \sum_{x,y} \max_{\forall i,j} [E(x+i, y+j) - \frac{1}{c}(|i| + |j|)]$$

$$\text{where } E(x,y) = \begin{cases} 1 & \text{if } Image(x,y) \ is\ an\ edge\ pixel \\ 0 & \text{Otherwise} \end{cases}$$

  - In our implementation SIFT features are also used when template is matched around the solution.
    - Weigh of an edge response is lower than a SIFT feature.

$$f_2 = w_1 f_1 + w_2 \sum_{x,y} \max_{\forall i,j} [S(x+i, y+j) - \frac{1}{c}(|i| + |j|)])$$

Multi-Population Genetic Algorithm

- Merging of Subpopulations :
  - Necessary to prevent replication.
  - How to measure distance between populations ?
    - Measure the distance between individuals.
  - How to merge populations.
    - Take the first half of the fittest individuals.
    - The number of individuals are decreased.
      - Produce random individuals to protect the balance.

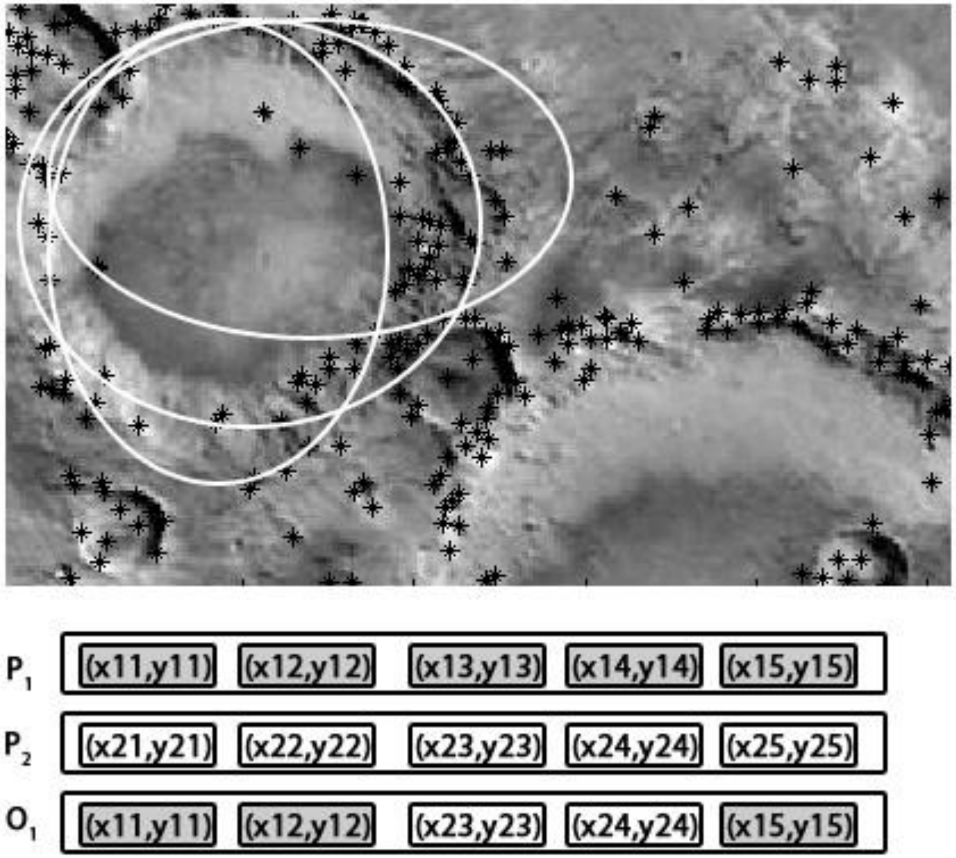
Multi-Population Genetic Algorithm

- Each individual lives on matching island.
  - Migraiton :
    - Choose the closest population.
  - Splitting :
    - Create new population when no population is close.
- Evolution : finding the fittest individuals.
  - Crossover :
    - Mate the individuals, produce offspings, keep fittest.
  - Mutation :
    - Randomly change the chromosome of the individual.
      - Low priority.
      - Inspired by evolutionary biology.

Multi-Population Genetic Algorithm

- Uniform crossover is implemented which exchanges the points determining ellipses (individuals).

Figure 6: Uniform crossover operation over two individuals P1 and P2 which produces the offspring O1



Basin Detection

- Need to determine the locations of basins to verify craters extracted.
- The drainage networks must be extracted from digital elevation data.
- Two solutions :
  - Hydrological approaches.
    - Depends on flow accumulation.
  - Morphological approaches.
    - Depends on shape of the basins.

Basin Detection

- Hydrological approach is chosen since impact craters are topographic basins.
  - When subject to enough rain, they become lakes.
- Two well-known hydrological approach :
  - Deterministic 8 (D8) [4]
    - Simulate the water on each cell flowing through lower elevation of highest slope in adjacent eight cells.
    - What happens on planar areas ?
      - Divergent flow.

Basin Detection

- Multiple flow direction model (MFDM) [5] :
  - Water in each cell flows through all lower elevation cells.
  - The distribution of the water is given by :

$$d_i = \frac{\max 0, S_i^w}{\sum_{j=1}^{8} \max 0, S_j^w}$$

  - Where Si is the slope of the adjacent cell, and w is the exponent determining weight.

Basin Detection

- We have adapted MFDM on Mars Digital elevation data (MDEM) :

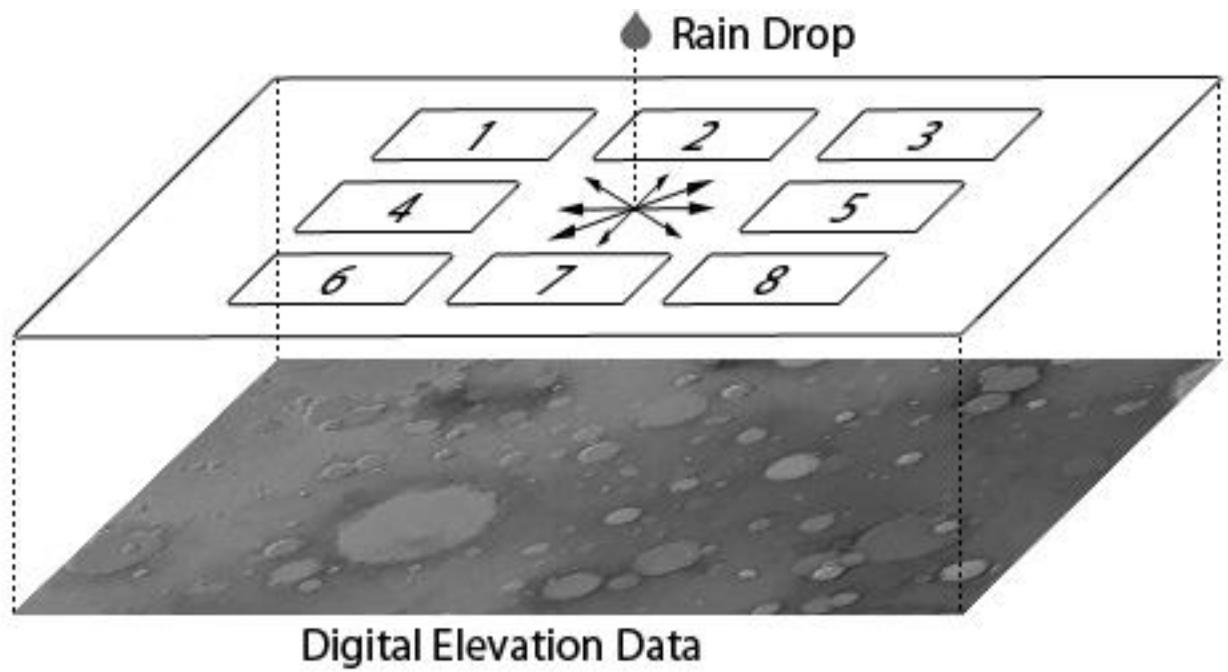


Figure 7: Sink source detection on Mars Digital Elevation Model

Crater Verification

- Need to merge the two result set :
  - Ellipses extracted from MDIM & MDEM
  - Basins extracted from MDEM.
- The ratio of the area of basins under ellipses and the area of ellipse is thresholded.
- Need to exclude duplicates.
  - The overlapping area of each pair of ellipses are compared to the area of the biggest one.

Experiments & Results

- Input Data : Digital Elevation and Image
- Available at NASA Web Map Server.
    - http://onmars.jpl.nasa.gov/
- Test Site
    - Heavily Cratered.
    - Craters are degraded.
    - Bounding Box : 7.42’ , -18.42’, 172.02‘ , -7.58’

Experiments & Results

- The Metrics used for assessing quality.
  - Proposed by [6]

$$Detection = \frac{100TP}{TP + FN}$$

$$Branching = \frac{FP}{TP}$$

$$Quality = \frac{100TP}{TP + FP + FN}$$

- TP : True Positives
- FP : False Positives
- FN : False Negatives

Experiments & Results

- Results for current algorithms :

	D	B	Q	Test Site	Ref.
Bue	74%	0.29	61%	Nontrivial	(Bue07)
Barlow	75%	0.00	75%	Nontrivial	(Bar88)
Barata	64%	1.65	31%	Nontrivial	(Bar04)
Kim	88%	0.15	78%	Trivial	(Kim05)

- Kim uses test sites that do not involve deformed craters.
- Barlow Catalog is manually prepared.

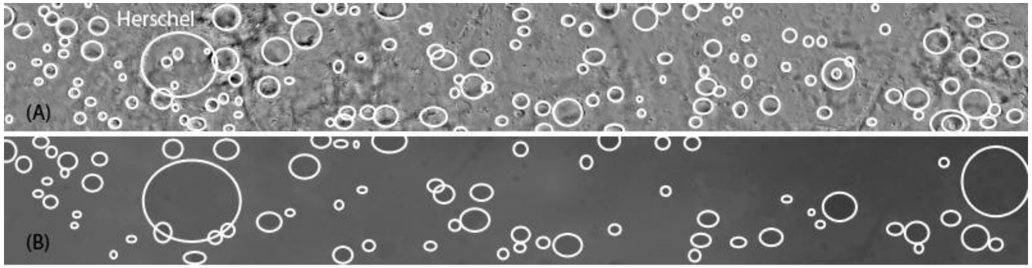
Experiments & Results

- Results for the algorithm we have proposed:
  - Detection = 73%
    - Close to best performing Algorithm.
  - Branching = 0.26
    - Best Branching Factor in the literature.
  - Quality = 61%
    - Close to best performing Algorithm.

Conclusion & Future Work

- Developed Flexible & Robust algorithm.
  - Flexible : Fitness function of MPGA can be improved.
  - Robust : Experiments have shown improvements.
- Future Work :
  - Curvature values could be incorporated into fitness evaluation of a crater.

Figure 8: Craters detected around famous Herschel crater.



References

- [Low99] D. G. Lowe, Object Detection from local scale-invariant features, Proceedings of the International Conference on Computer Vision, pp. 1150-1157, 1999.
- [Yao05] J. Yao, N. Kharma, P. Grogono, A multipopulation genetic algorithm for robust and fast ellipse detection , Pattern Analysis & Applications, vol. 8 pp. 149-162, 2005.
- [Man02] T. Mainzer, Genetic algorithm for shape detection, Technical report no. DCSE/TR-2002 06, University of West Bohemia, 2002.
- [Cal84] J. F. O'Callagnan, D. M. Mark, The extraction of drainage networks from digital elevation data, Comput. Vis. Graph. Image Process., vol. 28, no. 3, pp. 328-344, Dec. 1984.
- [Fre91] T.G. Freeman, Calculating catchment area with divergent flow based on a regular grid, Computer and Geoscience, pp.413-422, 1991.
- [Shu99] J. A. Shufelt, Performance evaluation and analysis of monocular building extraction from aerial imagery, IEEE Trans. Pattern Anal. Mach. Intell., vol. 21, no. 4, pp. 311-326, 1999.
- [Bar88] N. G. Barlow, Crater size-distributions and a revised Martian relative chronology, Icarus, vol. 75, no. 2, pp. 285-305, 1988.
- [Bue07] B. D. Bue, T. F. Stepinski Machine Detection of Martian Impact Craters From Digital Topography Data, IEEE Transactions on Geoscience and Remote Sensing, Vol.45, pp.265-274, 2007.

Thank you for your attention.
Any questions ?